2010 Report by Statewide Bridge Section

Hydrology and Hydraulics Review

Devils Creek Culvert
Kodiak Airport

July 2, 2010

Alaska Department of Transportation and Public Facilities
Statewide Design and Engineering Services Division

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Introduction

The Statewide Bridge Section was asked to evaluate the structural and hydraulic sufficiency of a concrete box culvert at the Kodiak Airport improvement project. The culvert routes Devils Creek beneath Runway 7/25 and Taxiways "F" and "D". The creek then continues through a man-made channel alongside Aprons A and B before discharging to the Buskin River.

The Bridge Section sent two inspectors – a hydraulics engineer and a structural engineer – to perform a visual assessment of the structure. The inspection was conducted on March 9, 2010, and led to two key findings:

- Rebar is exposed along most of the culvert invert.
- Devils Creek culvert has overtopped in the past.

The most recently overtopping event occurred during the week of October 4-10, 2009, when a severe storm in Kodiak partially flooded the runways. This was an extreme hydrologic event, however, Kodiak Maintenance and Operations (M&O) crews report that localized flooding near the Devils Creek culvert inlet is fairly common. It is often the result of ice or debris accumulation at the inlet.

This report provides a summary of our inspection observations and presents two betterment alternatives – replacement and rehabilitation – for your consideration.

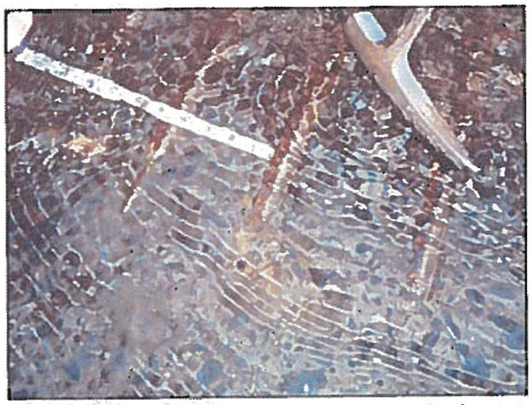
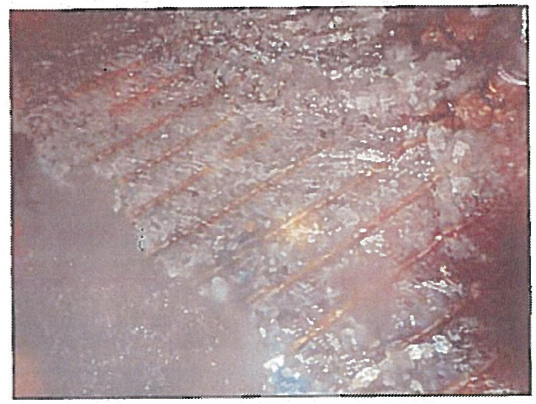
Inspection Observations

Ice was present in the channel and inside the culvert at the time of the March 9, 2010 site visit, but did not hinder visual inspection of the structure. Photographs from the inspection are included as attachments.

Structural Observations

The Devils Creek concrete box culvert is nearly 825 ft long and features two 10 ft wide by 6 ft high "bays". The culvert features wing walls at both ends. As-built drawings are available for the upper one third (extension section) of the culvert, but not for the lower two thirds.

The March 9, 2010 inspection revealed that reinforcing steel is exposed along much of the culvert length. Longitudinal reinforcing bars were also visible in a few locations. The loss of the protective concrete cover is due primarily to abrasion by passing gravels and cobbles during high flows. According to M&O staff, the culvert was visually inspected about 15 years ago and, at that time, there was no indication of exposed reinforcing steel.

FIGURES 1&2. Exposed rebar along the invert of the Devils Creek culvert (March 9, 2010).

Other structural observations include"

- Spalling of the concrete at the outlet,
- Cracks with efflorescence along the top of the culvert,
- Seepage at joints and through form tie holes, and
- "Map cracking" of concrete.

<u>Hydraulics Observations</u>

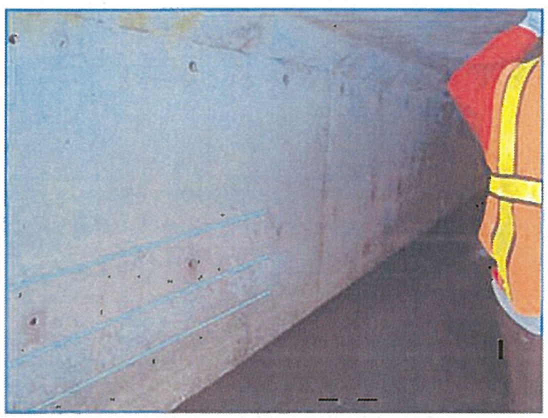
A "debris rack" at inlet appears to negatively affect hydraulic performance during floods by impeding flow.

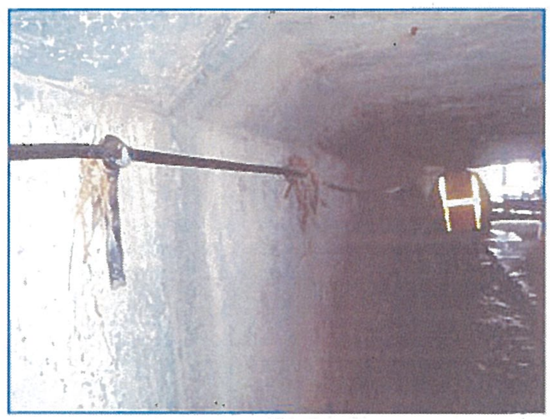
FIGURE 3. The inlet of the Devils Creek Culvert at the Kodiak Airport (March 9, 2010).

According to M&O crews, the reach above the culvert produces a lot of woody debris. Much of this wood reportedly comes from the remnants of an old timber culvert that once covered the creek. To reduce the potential for blockages *inside* the culvert barrels, M&O fabricated a near-vertical debris rack at the inlet using 18 inch wide sheet piling material. This is a wise provision that greatly simplifies the mechanical removal of debris. Unfortunately, the provision also contributes to flooding during extreme flood events. For example, M&O crews reported that during the October 2009 the area of inundation diminished after the culvert inlet was cleared of debris.

Icing in the channel and at the inlet can also adversely affect the hydraulic performance of the culvert. During the March 9, 2010 inspection, a frazil ice terrace was present at the inlet. It is likely that the steel sheet piling promotes ice growth and the presence of debris encourages frazil ice accumulation.

Insight into flood stage frequency can be gained from water stains inside the culvert, particularly at mid-length. For this hydraulically "long" culvert, the energy grade line, hydraulic grade line, and culvert slope should be parallel over much of the length. This is also referred to as "normal depth" conditions. Water stains (at mid length) can therefore be used as a "reality check" to evaluate hydraulic modeling results. (While not a precise form of calibration, it serves as a reasonable surrogate to calibration for a planning/scoping level of analysis.)





FIGURES 4&5. Water "stains" can offer insights into flood flow stages inside the culvert. Drift on the utility hooks similarly serve as high water indicators.

Near the inlet, we noted debris on a utility hook *near the top of the culvert!* This indicates the culvert has flowed near full *at this location* in the past. Given the close proximity of this debris to the inlet, it is possible the debris was deposited during a short "pulse" of water, such as following the release of stored water behind a debris blockage.

A waterfall downstream of the culvert serves as a downstream boundary control, simplifying the hydraulic modeling effort. The waterfall is probably a natural barrier to upstream fish passage, but this assessment should be confirmed with a local area biologist.

An 18 inch diameter corrugated metal pipe (bituminous coated) enters the box culvert from the west, approximately 450 ft upstream from the outlet.

Hydrology & Hydraulics

Peak flow estimates were needed to evaluate the hydraulic capacity of the existing culvert. I used regression equations published by the US Geological Survey in the USGS Water-Resources Investigations Report 03-4188 (Curran 2003) to compute flow estimates. The variables listed below were taken from a 1:63,360 scale USGS quadrangle map and from maps published in a separate USGS report, Water-Resources Investigations Report 93-4179 (Jones and Fahl 1994).

A, drainage area =	4 square miles
ST, area of lakes and ponds (storage) =	0.2 percent
P, mean annual precipitation =	100 inches
J, mean minimum January temperature =	24 degrees Fahrenheit

The resultant peak flow estimates for Devils Creek are listed below:

% Chance Flood	Q_T Recurrence Interval	Flow Rate
50%	Q_2	590 cfs
20%	Q_5	840 cfs
10%	Q_{10}	1,000 cfs
4%	Q_{25}	1,210 cfs
2%	Q_{50}	1,370 cfs
1%	Q_{100}	1,520 cfs
0.5%	Q_{200}	1,690 cfs
0.2%	Q_{500}	1,890 cfs

I developed a one-dimensional hydraulics model using the U.S. Army Corps of Engineer's HEC-RAS 3.1.3 River Analysis System program, and used its culvert modeling function to evaluate the existing structure and two betterment alternatives. Survey data for the creek was unavailable, so channel geometry was estimated from on-site observations and photo reconnaissance. Slope information came from a combination of as-built drawings and measurements taken in the field using a hand level. A slope of five percent was used for the channel.

Field observations suggest that the stream bed is composed of sands, gravels, cobbles, and small boulders. Manning's "n" values of 0.03 for the channel and 0.045 for the banks were selected based upon engineering judgment. A Manning's "n" value of 0.014 was used for the culvert sides and top. A slightly higher value of 0.02 was used for the bottom to simulate the exposed rebar.

The model indicates that the existing culvert, *without any obstructions at the inlet*, might be capable of passing a 2% chance flood (50-year), but I feel the 4% chance flood (25-year) is a more reasonable capacity estimate.

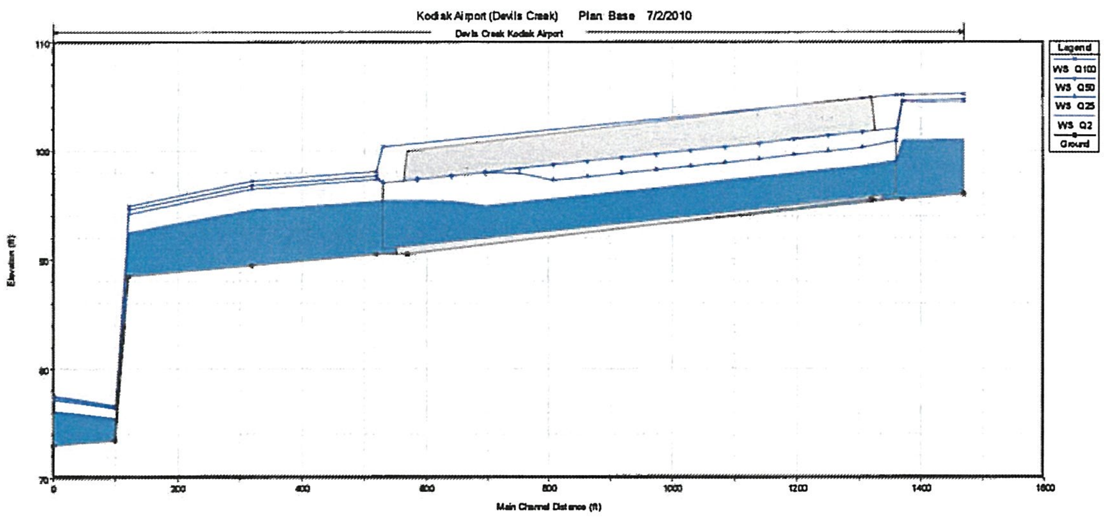


FIGURE 6. Profiles for the 2-year & 25-year (partially full), the 50-year (full), and the 100-year flood (over-topping). These profiles assume no blockages or other flow impedance at the inlet.

Remedial Strategies and Alternatives

While the culvert is carrying loads now, the ongoing loss of concrete cover over the reinforcing steel along the culvert bottom will eventually become a significant structural problem. Recollections by M&O staff that that reinforcing steel was not exposed 15 years ago during prior inspection are informative. It is likely that the exposure of rebar to flowing water (and the associated bedload transport) has accentuated abrasion along the concrete floor.

We explored two betterment alternatives and present these below for consideration. The two alternatives would satisfy different sets of design objectives. The first alternative (replacement) would correct all noted deficiencies at the site. A major construction project across Runway 7-25 and Taxiway "F" would introduce a disruption to airport operations, however. The second alternative (rehabilitation) seeks to avoid that disruption and would preemptively address the (eventual) structural deficiency of the culvert. The rehabilitation option would lead to greater potential for flood-related disruptions at the airport, however.

<u>Alternative 1- Replacement Structure</u>

For the replacement structure, we added another cell, resulting in cast-in-place box culvert with <u>three</u> 6 ft x 10 ft cells. This concept increases the cross-sectional opening by 33%, greatly improving the overall capacity of the culvert. The HEC-RAS model was rerun using this wider culvert geometry and indicates that the alternative would pass a 1% chance flood. While this alternative would substantially reduce the maintenance burdens at the inlet, it would not eliminate the need to keep the inlet clear of debris during floods.

After reviewing an aerial photograph, it appears that this replacement structure could be installed with a straight alignment west of the existing structure. This concept would allow the existing structure to route water around the construction zone while a majority of the new structure is constructed. Special provisions to dewater the inlet and outlet ends of the new culvert would still be required, though.

For this conceptual layout, the new culvert would be 930 ft long. This is longer than the existing culvert, but the extra length helps to avoid spatial conflicts with the existing culvert and would accommodate paving improvements near the outlet.

As with the existing structure, the incorporation of debris control provisions at the inlet is warranted. My preference would be a debris rack system with longer, narrower vertical members that extend upstream at an shallow angle. Sloping extensions of the culvert center walls, sometimes referred to as "debris fins," could be added for support.

An alternative approach to debris control would be to drive piles into the channel upstream of the culvert and then armor the overbank areas for bypass flows. A key design consideration for either approach is the "maintainability" of the debris rack. Kodiak M&O staff have mentioned that the limited "reach" of a standard backhoe inhibits their ability to clear the culvert.

<u>Alternative 2 – Rehabilitation of the Existing Structure with Inlet Improvements</u>

This alternative would involve constructing a new "floor" inside the existing culvert. The new invert would be 3 inches higher than before, resulting in a cross-sectional area reduction of nearly 4 percent. The peak flow capacity of the culvert would also be reduced, resulting in a structure capable of handling only a 10% chance flood.

For this alternative, I would favor the driven pile debris control upstream of the culvert with armored overbank areas for bypass flows. This would maximize the potential for keeping the waterway opening at the inlet free of debris and ice.

<u>REFERENCES</u>

Curran, J.H., Meyer, D.F., and Tasker, G.D. (2003). Estimating the Magnitude and Frequency of Peak Streamflows for Ungaged Sites on Streams in Alaska and Conterminous Basins in Canada, U.S. Geological Survey Water-Resources Investigations 03-4188. Anchorage, Alaska.

Jones, S.H. & Fahl, C.B. (1994). Magnitude and Frequency of Floods in Alaska and Conterminous Basins of Canada, U.S. Geological Survey Water-Resources Investigations Report 93-4179, Plates 1 & 2. Anchorage, Alaska.

ATTACHMENTS

1. ~~Cost Estimates~~ removed
2. AutoCAD Drawings
3. Inspection Photographs

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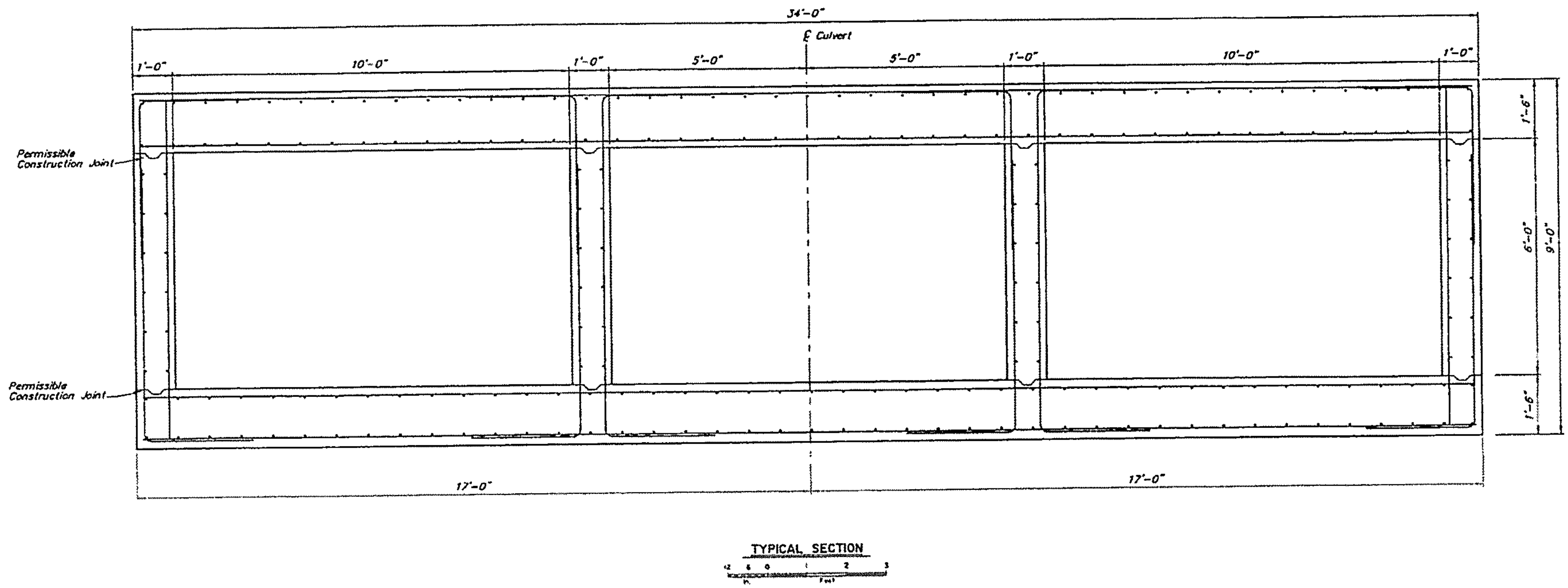
STATE	PROJECT DESIGNATION	YEAR	SHEET NO.	TOTAL SHEETS
ALASKA		2010		

OPTION 1

REPLACEMENT CULVERT
$12,000,000



TYPICAL SECTION

DESIGNED BY:	CHECKED:	
DRAWN BY:	CHECKED:	
QUANTITIES BY:	CHECKED:	

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES
BRIDGE SECTION

KODIAK AIRPORT CULVERT
AIRPORT ROAD
TYPICAL SECTION

BRIDGE NO.
DWG. NO. 1

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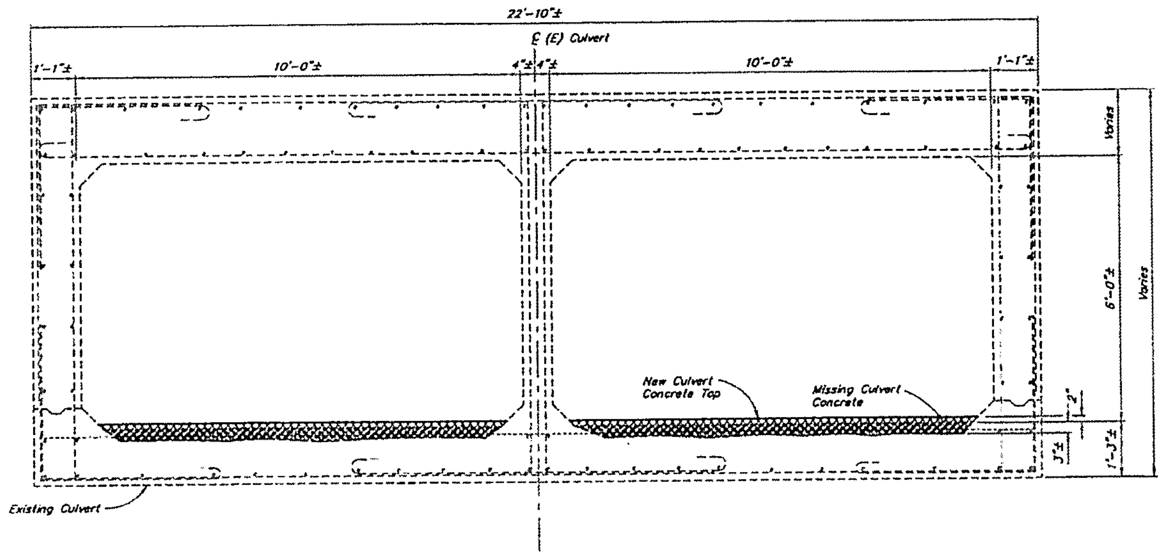
STATE	PROJECT DESIGNATION	YEAR	SHEET NO.	TOTAL SHEETS
ALASKA		2010		

OPTION 2

REHABILITATE EXISTING CULVERT
$2,500,000



TYPICAL SECTION

DESIGNED BY:	CHECKED:
DRAWN BY:	CHECKED:
QUANTITIES BY:	CHECKED:

STATE OF ALASKA
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BRIDGE SECTION

KODIAK AIRPORT CULVERT
AIRPORT ROAD
TYPICAL SECTION

BRIDGE NO.
DWG. NO. 1

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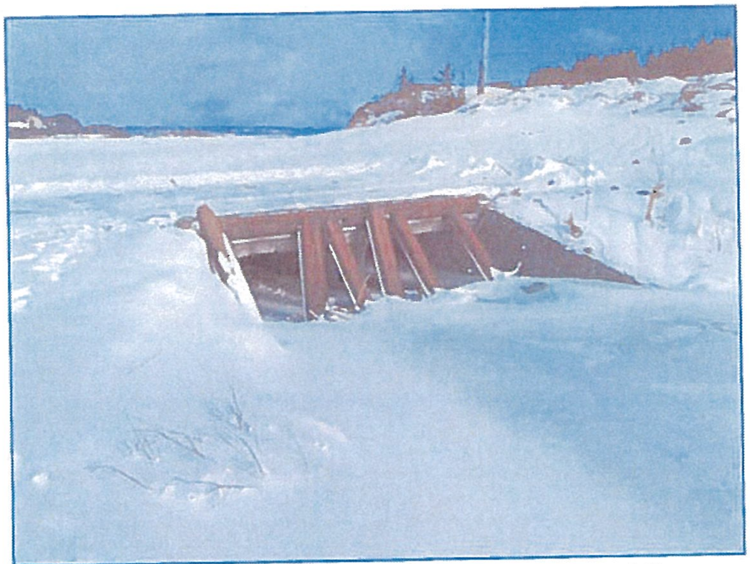

FIGURE 1. Culvert inlet and "debris rack".

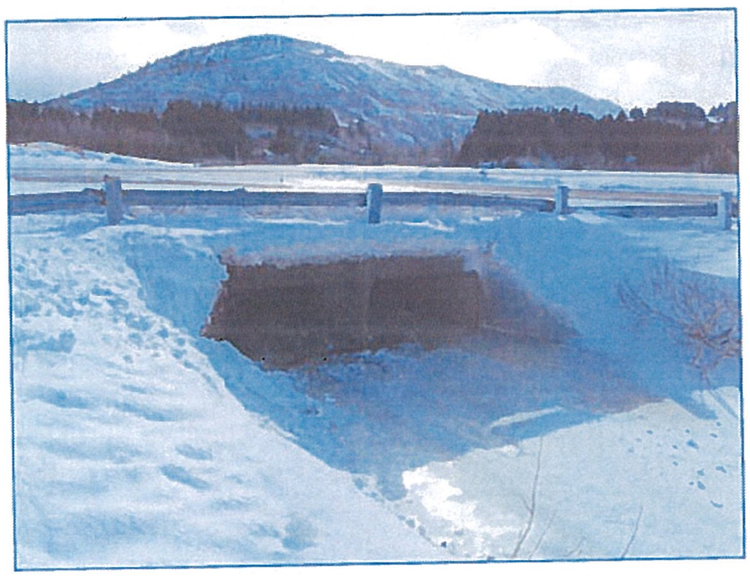

FIGURE 2. Culvert outlet.

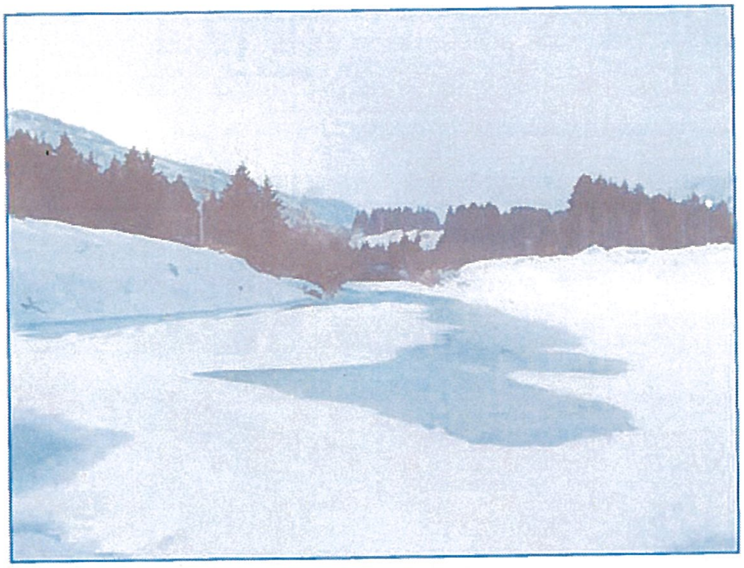

FIGURE 3. Upstream view from the culvert inlet. According to M&O staff, the width of the channel immediately upstream of the culvert has increased over time.

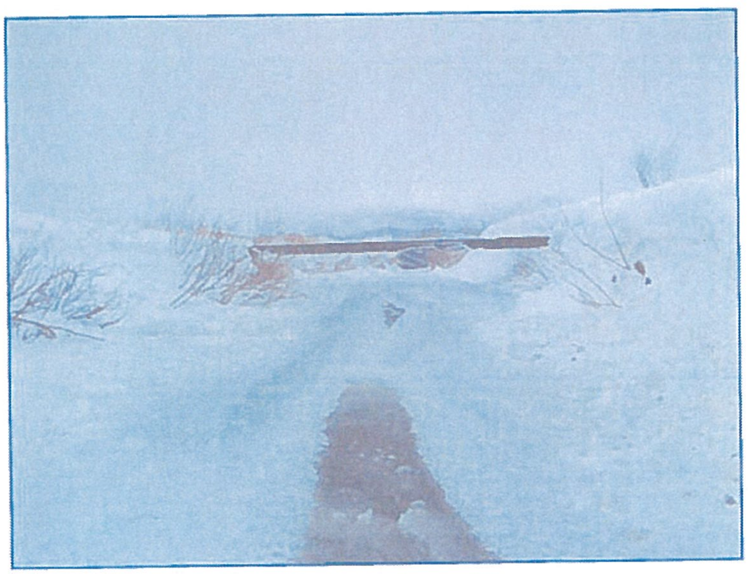

FIGURE 4. Downstream view of Devils Creek from the culvert outlet.

FIGURE 5. Minor concrete spalling at the culvert outlet.

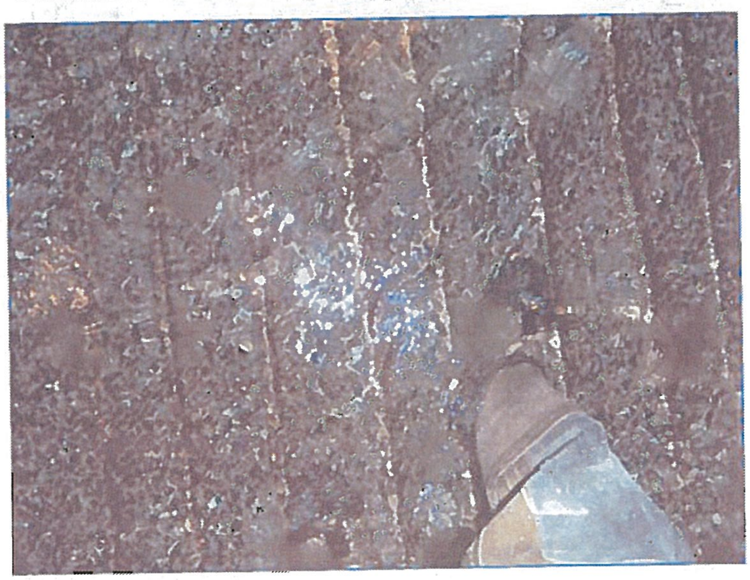

FIGURE 6. Exposed rebar along the culvert invert.

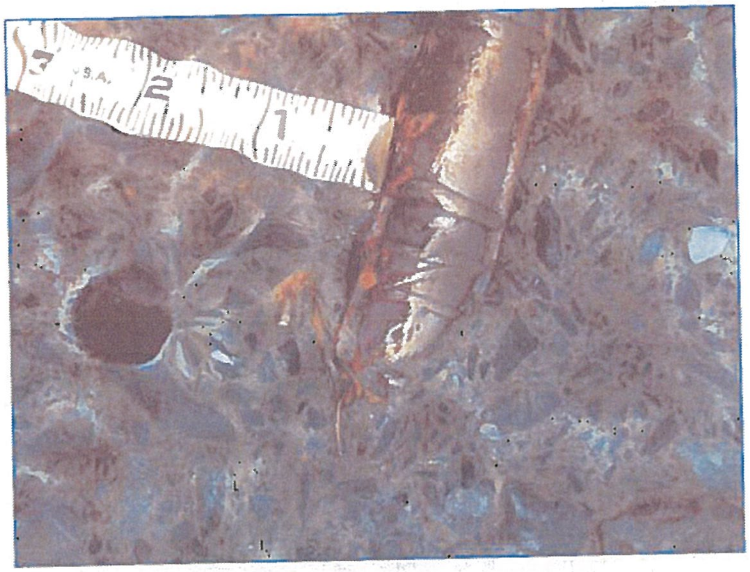

FIGURE 7. Rebar marked with "N" on the invert.

FIGURE 8. Note that longitudinal bars are also exposed in some areas.

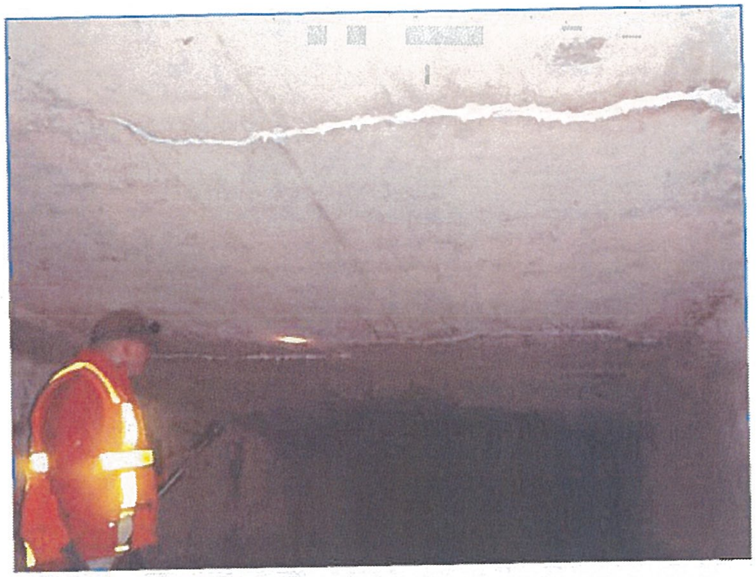

FIGURE 9. Efflorescence evident with cracks.

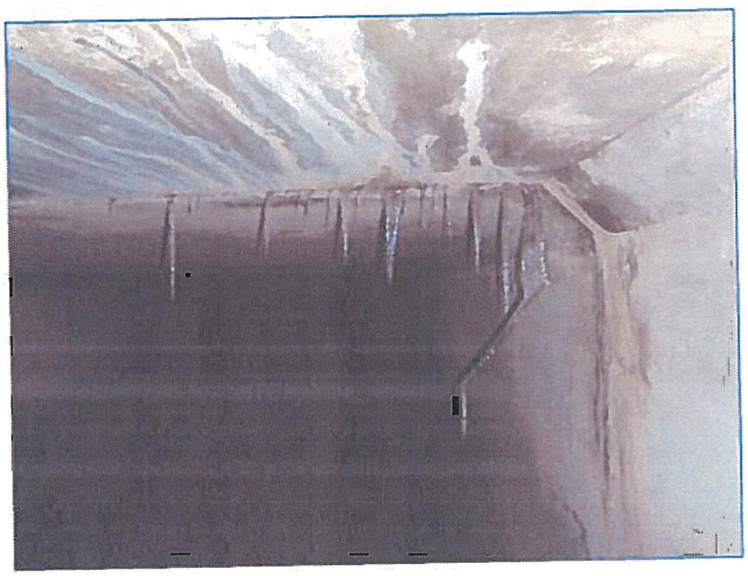

FIGURE 10. Minor seepage (icicles) and efflorescence at a joint.

FIGURE 11. "Map cracking" along the top of structure, mostly evident in the upstream 1/3 of the culvert

FIGURE 12. Minor seepage and surface damage through form tie holes. Also shown here is an abandoned utility cable that is not in service.

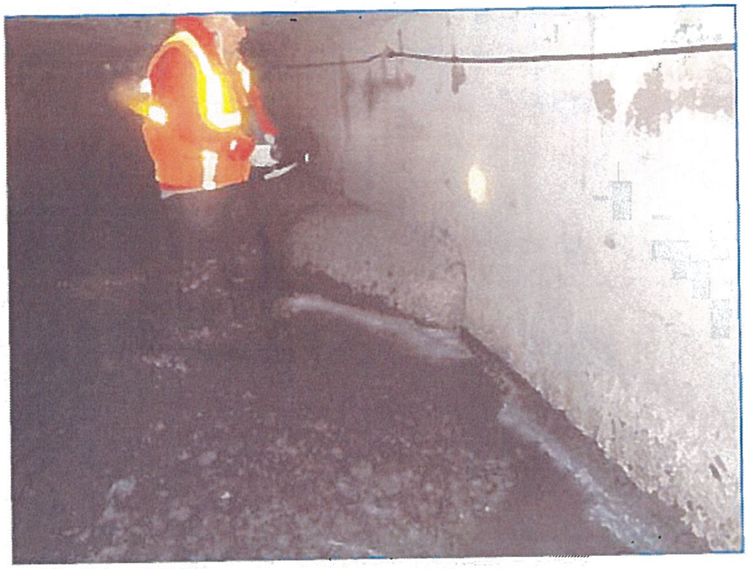

FIGURE 13. Note the encased utility along invert.

FIGURE 14. Reinforcing steel at the location where the encased utility enters/leaves the box culvert.

FIGURE 15. "Debris rack" at the culvert inlet with ice accumulation.

FIGURE 16. A frazil ice terrace at the culvert inlet.

FIGURE 17. Debris caught on utility hooks near the inlet. This high water mark is near the inlet. Therefore, it is unclear whether this represents "normal depth" conditions or a short-duration "pulse" of water, such as that which would follow a debris blockage removal at the inlet.

FIGURE 18. Though difficult to see in the photograph, water "stains" on the sides of the culvert are useful indicators of flow depths and recurrence. Shown here are indications that flow depth regularly exceeds the mid-height (form tie) holes.

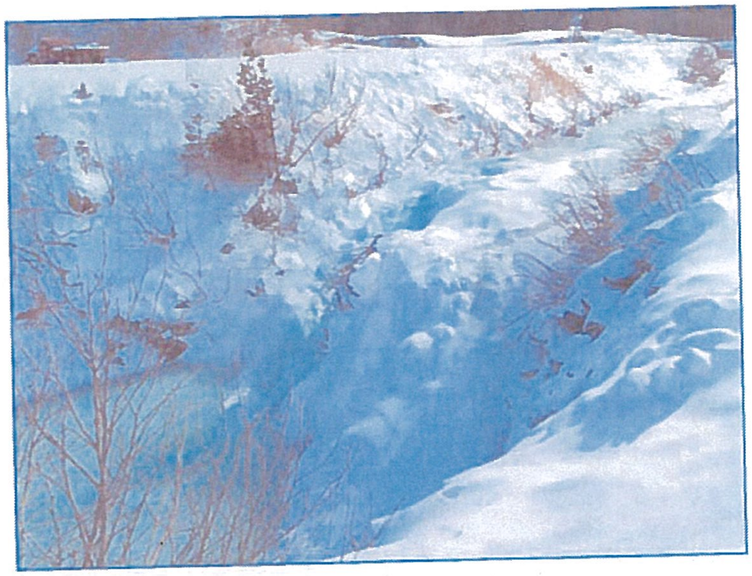

FIGURE 19. Waterfall downstream of the culvert.

FIGURE 20. Culverts beneath an access road, downstream of the concrete box culvert.

FIGURE 21. Maintenance access road/bridge upstream of the culvert. Note the debris accumulation at the bridge.

FIGURE 22. View of the channel upstream of the culvert between the M&O access road and the Rezanof Drive culvert.

FIGURE 23. Upstream culvert beneath Rezanof Drive with debris accumulation at the inlet.

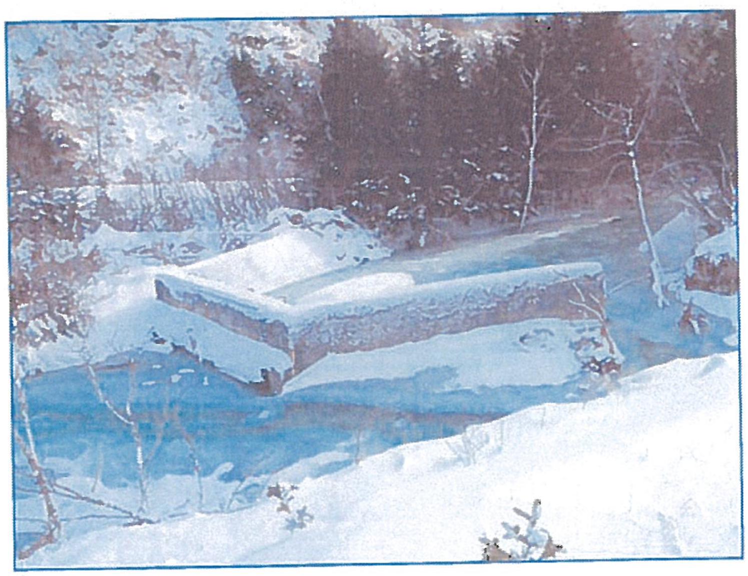

FIGURE 24. A concrete structure upstream of Rezanof Drive.

FIGURE 25. Another view of the concrete structure upstream of Rezanof Drive.

FIGURE 26. Active erosion along an access road upstream of Rezanof Drive. The erosion is caused by flow around the concrete structure.

FIGURE 27. An 18-inch corrugated metal pipe entering the river-left barrel approximately 450 ft upstream of the outlet. This corresponds to the drainage swale between the runway and taxiway.

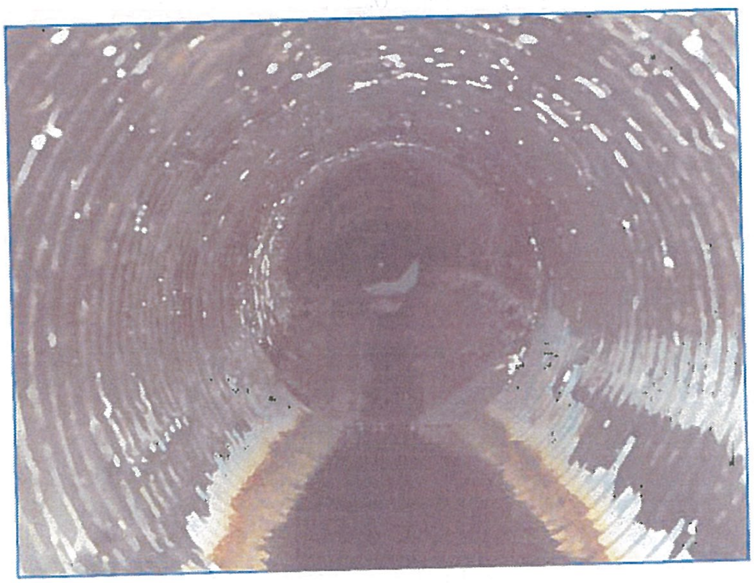

FIGURE 28. Minor corrosion and loss of bituminous coating.

FIGURE 29. Weir on Devils Creek (Photo by others)